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RESEARCH ARTICLE

Streamflow alteration and habitat ramifications for a threatened fish species in the Central United States

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Abstract

In the Central United States, the Arkansas darter (*Etheostoma cragini*) is listed as a threatened fish species by the State of Kansas. Survival of the darter is threatened by loss of habitat caused by changing streamflow conditions, in particular flow depletion. Future management of darter populations and habitats requires an understanding of streamflow conditions and how those conditions may have changed over time in response to natural and anthropogenic factors. In Kansas, streamflow alteration was assessed at 9 U.S. Geological Survey streamgages in 6 priority basins with no pronounced long-term trends in precipitation. The assessment was based on a comparison of observed (O) and predicted expected (E) reference conditions for 29 flow metrics. The O/E results indicated a likely or possible diminished flow condition in 2 basins; the primary cause of which is groundwater-level declines resulting from groundwater pumping for irrigated agriculture. In these 2 basins, habitat characteristics adversely affected by flow depletion may include stream connectivity, pools, and water temperature. The other 4 basins were minimally affected, or unaffected, by flow depletion and therefore may provide the best opportunity for preservation of darter habitat. Through the O/E analysis, anthropogenic streamflow alteration was quantified and the results will enable better-informed decisions pertaining to the future management of darters in Kansas.

KEYWORDS

fish, habitat, High Plains aquifer, predictive models, streamflow alteration, streamflow metrics

1 | INTRODUCTION

Streamflow (hereafter flow) is a primary determinant of physical habitat in rivers and streams as well as the composition, abundance, and distribution of resident aquatic organisms (Bunn & Arthington, 2002; Poff et al., 1997). Alteration of the natural flow regime can adversely affect the ecological integrity of rivers and streams. For example, Poff and Zimmerman (2010), in an extensive review of flow alteration and ecological response (165 papers published over 4 decades), determined that fish abundance and diversity consistently decreased in response to flow alteration (both increased and decreased flow magnitude). Moreover, they concluded that the risk of ecological change increased as the magnitude of flow alteration increased. Carlisle, Wolock, and Meador (2011), in a study of about 250 sites located throughout the contiguous United States, concluded that the likelihood of impairment for fish communities doubled with increasing severity of reduced flows. In the Great Plains of the Central United States, declining fish diversity has been attributed, at least in part, to habitat fragmentation and flow alteration (Hoagstrom, Brooks, & Davenport, 2011; Perkin et al., 2015). Fundamental for addressing the issue of ecological response to flow alteration in an area of interest is a quantification of the divergence of observed flow conditions from expected reference (least-disturbed) conditions.

In the Central United States, the Arkansas darter (*Etheostoma cragini*; hereafter darter) is listed as a threatened fish species by the State of Kansas (Haslouer et al., 2005). At the federal government level, the darter was a candidate species for listing as endangered or threatened; however, in 2016, the U.S. Fish and Wildlife Service decided that listing was not warranted (U.S. Fish and Wildlife Service, 2016). Loss of habitat caused by changing flow conditions is a primary threat to the survival of the darter. Specifically, a reduction of flow caused by various factors (e.g., groundwater withdrawals, decreased precipitation, change in runoff conditions, land-use change, and climate change) may adversely and perhaps irreversibly affect the remaining darter populations in the State (Eberle & Stark, 2000; Falke et al., 2011; Hoagstrom et al., 2011). Habitats of particular interest are located in southwest and south-central Kansas. Six priority basins containing darter habitat have been identified by the U.S. Fish and Wildlife Service and the Kansas Department of Wildlife, Parks and Tourism and include the following: the Cimarron River (of which Crooked Creek is a subbasin), Rattlesnake Creek, the North Fork Ninnescah River upstream from Cheney Reservoir, the South Fork Ninnescah River, the Medicine Lodge River, and the Chikaskia River (Figure 1).

In this study, statistical modelling was used to assess flow alteration at nine selected U.S. Geological Survey (USGS) streamgages (Table 1; also referred to as sites) that provide an indication of conditions within the six priority basins (Figure 1) in southwest and south-central Kansas. Specific objectives of the study were twofold: first, to assess the departure of observed flow conditions from expected reference conditions for selected flow metrics and, second, to discuss the ramifications of flow alteration for management of darter populations and habitats.

2 | METHODS

Anthropogenic changes to the flow regime in the priority basins were assessed using the reference condition approach (Bailey, Norris, & Reynoldson, 2004; Carlisle, Falcone, Wolock, Meador, & Norris, 2010), which is based on the principle that expected reference conditions for basins influenced by hydrologic modifications (e.g., groundwater withdrawals and land-use change) can be predicted by using statistical models developed for a population of reference (i.e., least disturbed) basins. With this approach, anthropogenic changes at selected streamgages were quantified as the difference between the observed (O) flow conditions and the predicted expected (E) reference conditions.

2.1 | Study area

The study area in southwest and south-central Kansas includes all or part of the basins for the Cimarron River, Rattlesnake Creek, North Fork Ninnescah River, South Fork Ninnescah River, Medicine Lodge River, and Chikaskia River (Figure 1). This area is located within the High Plains, Southwestern Tablelands, and Central Great Plains level III ecoregions (U.S. Environmental Protection Agency, 2013). Average annual precipitation in the study area increases from about 40–50 cm in the west to about 75 cm in the east (High Plains Regional Climate Center, 2014; Sophocleous, 1998). Spatially averaged annual precipitation for the basins for 1951 through 2013, derived from Parameter-elevation Relationships on Independent Slopes Model monthly precipitation data (Daly et al., 2008), was characterised by substantial year-to-year variability with no pronounced long-term trends (Juracek, 2015). Land use in the basins mostly is a mix of cropland and grassland (Figure 1; Jin et al., 2013).

The High Plains aquifer (Figure 2) underlies all or most of the basins of the Cimarron River, Rattlesnake Creek, North Fork Ninnescah River, and South Fork Ninnescah River. However, the aquifer is not present in most of the Medicine Lodge and Chikaskia River Basins. The aquifer is characterised as a water-table aquifer that primarily consists of near-surface sand and gravel deposits (Weeks, Gutentag, Heimes, & Luckey, 1988). Extensive use of groundwater from the aquifer, primarily for irrigated agriculture, began in the 1950s and continues to the present (Gutentag, Heimes, Krothe,

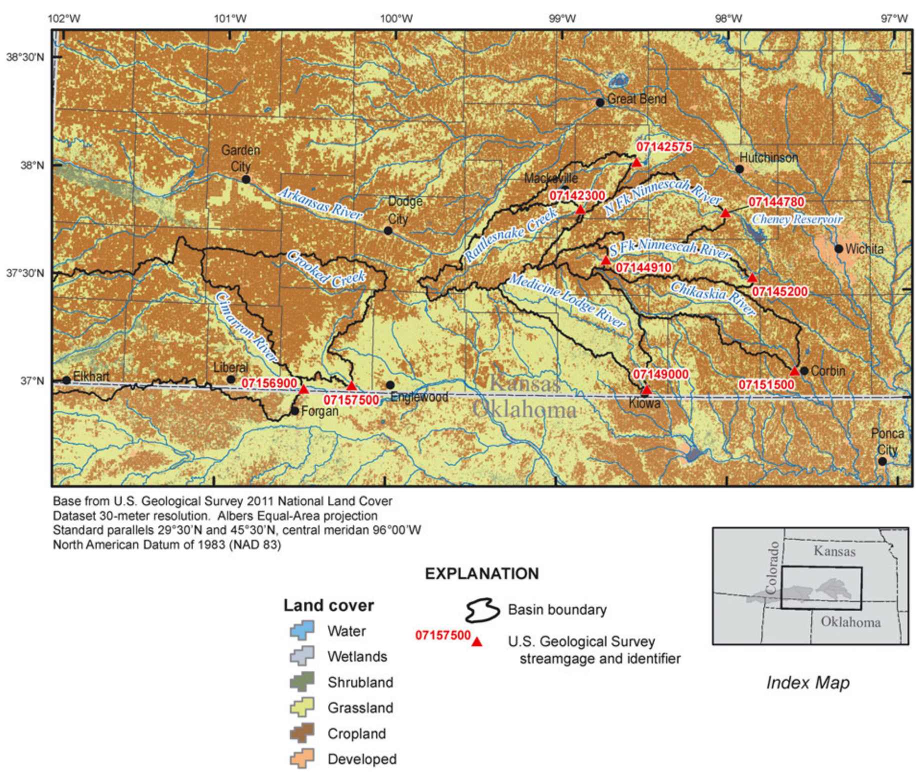

FIGURE 1 Basin boundaries, nine selected U.S. Geological Survey streamgages, and land use (2011), southwest and south-central Kansas. Source of land-use data: Jin et al. (2013) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Streamgages for which flow alteration was assessed in this study. Location of streamgages is shown in Figure 1

USGS[a] streamgage number	USGS streamgage name	Drainage area[b,c] (km^2)	Period of record
07142300	Rattlesnake Creek near Macksville, KS	1,870	1960–2014
07142575	Rattlesnake Creek near Zenith, KS	2,790	1974–2014
07144780	N.F. Ninnescah River above Cheney Reservoir, KS	2,060	1966–2014
07144910	S.F. Ninnescah River near Pratt, KS	315	1981–2014
07145200	S.F. Ninnescah River near Murdock, KS	1,550	1951–2014
07149000	Medicine Lodge River near Kiowa, KS	2,290	1939–2014
07151500	Chikaskia River near Corbin, KS	2,110	1951–2014
07156900	Cimarron River near Forgan, OK	17,100	1966–2014
07157500	Crooked Creek near Englewood, KS	3,670	1943–2014

[a]USGS = U.S. Geological Survey.

[b]Drainage area computed using the watershed boundary dataset component of The National Map (U.S. Geological Survey, 2010).

[c]Substantial parts of the Rattlesnake Creek, North Fork Ninnescah River, South Fork Ninnescah River, Cimarron River, and Crooked Creek Basins may be noncontributing.

Luckey, & Weeks, 1984; Kansas Water Resources Board, September 1958, January 1960; Kenny & Juracek, 2013). Groundwater withdrawals for irrigation far in excess of natural recharge are the primary cause of groundwater-level declines in the aquifer (Gutentag et al., 1984; Whittemore, Butler, & Wilson, 2016; Young, Macfarlane, Whittemore, & Wilson, 2005). In much of the Cimarron River Basin (of which Crooked Creek is a subbasin), groundwater levels have declined 15 to 45 m (50 to 150 ft) or more. Groundwater-level declines of 3 to 8 m (10 to 25 ft) or more have occurred in upstream parts of the basins of Rattlesnake Creek, the North Fork Ninnescah River, and the South Fork Ninnescah River (McGuire, 2014; Figure 2).

2.2 | Flow alteration assessment

Flow alteration was assessed using a set of flow metrics that are computed from daily flow time series and are indicative of key aspects of the flow regime (Carlisle et al., 2010). Metrics were selected, in part, based on knowledge of regional hydrology and the flow requirements of darters. Twenty-nine metrics were selected that represent various flow characteristics, including average flow (annual and monthly), daily flow variability, low and high flow (frequency, duration, and magnitude), and baseflow (Table 2).

Nine USGS streamgages, located within the priority basins, were targeted for assessment of flow alteration (Figure 1). Each of the target

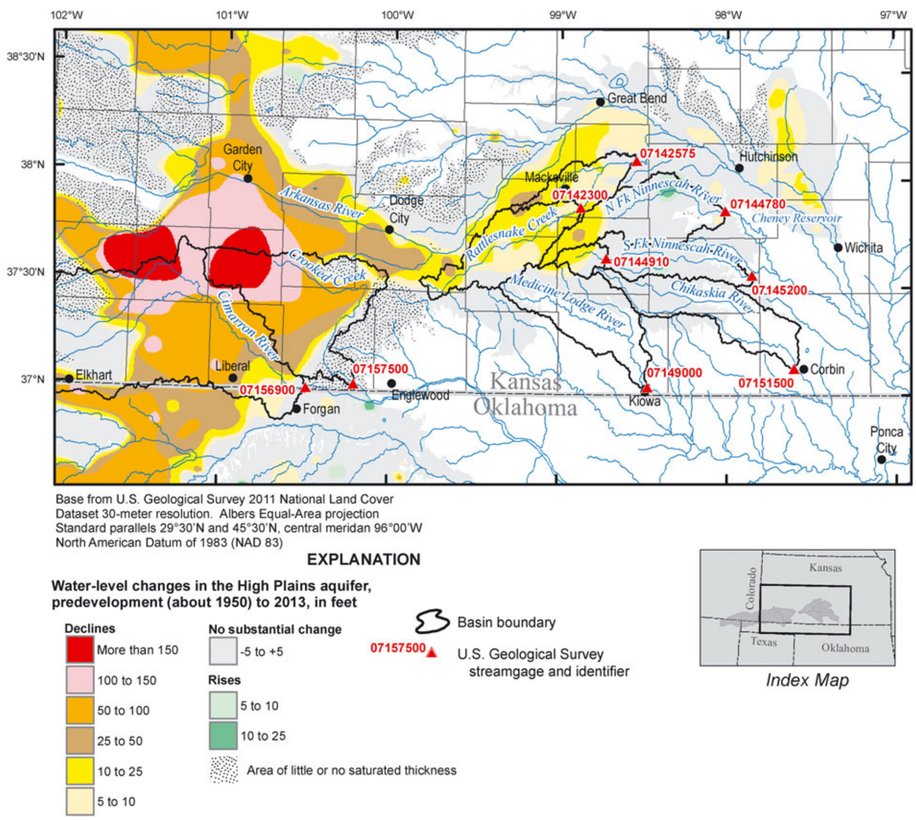

FIGURE 2 Groundwater-level changes in the High Plains aquifer, predevelopment to 2013. Source: McGuire (2014) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Flow metrics used in this study

Metric name	Description
P50	Median annual flow normalised by drainage area
CV_FLOW	Coefficient of variation of daily flows
AVG_JAN	Mean January flow normalised by drainage area
AVG_FEB	Mean February flow normalised by drainage area
AVG_MAR	Mean March flow normalised by drainage area
AVG_APR	Mean April flow normalised by drainage area
AVG_MAY	Mean May flow normalised by drainage area
AVG_JUN	Mean June flow normalised by drainage area
AVG_JUL	Mean July flow normalised by drainage area
AVG_AUG	Mean August flow normalised by drainage area
AVG_SEP	Mean September flow normalised by drainage area
AVG_OCT	Mean October flow normalised by drainage area
AVG_NOV	Mean November flow normalised by drainage area
AVG_DEC	Mean December flow normalised by drainage area
PUL_NO_P90	Average annual number of flow pulses larger than 90th percentile
PUL_NO_P75	Average annual number of flow pulses larger than 75th percentile
PUL_NO_P25	Average annual number of flow pulses less than 25th percentile
PUL_NO_P10	Average annual number of flow pulses less than 10th percentile
P10	10th percentile flow normalised by drainage area
P90	90th percentile flow normalised by drainage area
PER_BSFL[a]	Percentage of flow that is baseflow
PUL_LEN_P10	Average duration of flow pulses less than 10th percentile
PUL_LEN_P25	Average duration of flow pulses less than 25th percentile
PUL_LEN_P75	Average duration of flow pulses larger than 75th percentile
PUL_LEN_P90	Average duration of flow pulses larger than 90th percentile
PUL_FLOW_P10	Average flow of pulses less than 10th percentile, normalised by drainage area
PUL_FLOW_P25	Average flow of pulses less than 25th percentile, normalised by drainage area
PUL_FLOW_P75	Average flow of pulses larger than 75th percentile, normalised by drainage area
PUL_FLOW_P90	Average flow of pulses larger than 90th percentile, normalised by drainage area

[a]Renamed from metric M_L20 in Olden and Poff (2003).

streamgages provides long-term daily flow data that were collected as part of the USGS national streamgaging network using standard USGS methods (Turnipseed & Sauer, 2010). For each streamgage, the period of record through 2014 was at least 34 years (Table 1). The flow data are available online from the USGS National Water Information System (U.S. Geological Survey, 2015). Observed (O) values of the 29 flow metrics for each target streamgage were computed using daily flow data for the period of record (Table 1) downloaded from the National Water Information System using a program by Granato (2009). An understanding of shorter-term flow fluctuation (e.g., hourly) and its associated effects on the darter and its habitat, although possibly important, is not well-documented in the literature and may represent an opportunity for future research (Bevelhimer, McManamay, & O'Connor, 2014).

Estimates of the expected (E) reference value for each flow metric for each targeted streamgage were predicted with statistical models that use basin characteristics such as climate, topography, and soils as explanatory variables (Carlisle et al., 2010). Statistical models were developed using 1,443 previously identified streamgages (Falcone, Carlisle, Wolock, & Meador, 2010) with least-disturbed basins (i.e., reference quality) on perennial, intermittent, and ephemeral streams across the contiguous United States. For each reference site, 176 geospatial characteristics representing natural (i.e., excluding land cover and other anthropogenic activities) physical attributes of the contributing basin were computed (Falcone, 2011).

Separate random forest (RF; Cutler et al., 2007) models were developed for each flow metric using the 1,443 reference sites, with the observed metric as the dependent variable and the natural geospatial characteristics as predictors. The RF models were implemented in Matlab using a script by Jaiantilal (2009). Modelling proceeded as follows: First, 30 RF models, each with 1,000 trees, were fit using all 176 basin characteristics and a randomly selected subset of 90% of the reference sites. For each RF model, the importance of each predictor variable was computed by measuring the decrease in model performance as that variable was randomly permuted (Cutler et al., 2007). The 20 predictors with the highest average importance among the 30 initial models were selected for the final model. For each flow metric, the final model included 100 RF fits, each with 1,000 trees, trained on a randomly selected subset of 90% of the reference sites. For each RF model fit, 10% of the sites were set aside for validation of model performance and were selected in equal numbers from nine aggregated ecoregions of the contiguous United States (Falcone, 2011) to ensure even geographic distribution.

Model performance was evaluated using four independent (Pearson $r < 0.3$) criteria. These were Nash–Sutcliffe efficiency (Nash & Sutcliffe, 1970), percent bias (Moriasi et al., 2007), mean O divided by E (O/E) values (Carlisle et al., 2011), and the standard deviation (SD) of O/E values. These criteria were calculated on each randomly chosen set of 100 validation sites and then averaged for each flow metric. For simplicity, a single composite performance measure also was calculated for each metric by standardising the four criteria to a 0-to-1 scale and computing their sum, with higher scores indicating superior performance. All Nash–Sutcliffe efficiency negative values were set to 0 so that the range was bound between 0 and 1. Values for percent bias were bound between ± 100, divided by 100, and their absolute values were subtracted from 1. The bounds for mean O/E were 0 and 2. Values between 0 and 1 were unscaled, and values from 1 to 2 were subtracted from 2. The bounds for the *SD* of O/E were set at 0 and 0.5 and scaled from 0 to 1, where a value of 1 corresponds to a *SD* of 0 and a value of 0 corresponds to a SD of 0.5 or greater.

Flow alteration at the target sites for each of the 29 flow metrics (Table 2) was quantified as the ratio of the observed (O) value to the predicted expected (E) reference value. The four targeted streamgages (07142300, 07144780, 07149000, and 07151500) with least-disturbed basins were used to quantify uncertainty in estimates of E for the study area. Use of the four regional sites was thought to provide a more representative and meaningful estimate of error relative to estimates from the national set of reference sites. Ideally, the O/E values at least-disturbed sites would equal 1, but that was seldom the case due to error in modelling E. In general, O was within ±40% of E at the four least-disturbed sites in the study area, so this was used as a threshold beyond which anthropogenic alteration could be reliably distinguished from model error. Thus, for this study, flow metrics were considered anthropogenically altered only if O was either at least 40% larger (considered inflated) or at least 40% smaller (considered diminished) than E.

3 | RESULTS AND DISCUSSION

3.1 | Model performance

For the majority of the models (21 of 29) for the flow metrics, performance was either good or very good (Appendix 1) and these were the most predictable metrics (as defined by Eng et al., in press). Model performance was fair for seven metrics (Appendix 1). The model for the baseflow metric (PER_BSFL) performed poorly. Poor model performance for low-flow estimation has been reported elsewhere (Eng & Milly, 2007; Newman et al., 2015). On the basis of an assessment of regional variability in hydrologic model performance for the contiguous United States, Newman et al. (2015) concluded that the main factors affecting the variation in model performance were aridity, precipitation intermittency, snowmelt contribution, and runoff seasonality. In addition, other factors that contribute to poor model performance for low-flow and baseflow estimation include the inherent measurement error for low flows and a lack of good subsurface metrics that describe aquifer hydraulic properties.

3.2 | Flow alteration

In the study area, three sites were decidedly least disturbed as all 29 flow metrics were neither diminished nor inflated. These three sites were the North Fork Ninnescah River above Cheney Reservoir (station 07144780), the Medicine Lodge River near Kiowa (station 07149000), and the Chikaskia River near Corbin (station 07151500; Table 3). The first site is located in a basin where offsetting decreases (upstream) and increases (downstream) in groundwater levels (Figure 2) may have resulted in minimal net change in flow at the streamgage. However, in the upstream part of the basin where groundwater-level decreases were pronounced, flow may have been affected. The latter two sites are located in basins that are minimally affected by groundwater withdrawals as the High Plains aquifer is not present in much of the Medicine Lodge and Chikaskia River Basins (Figure 2). A fourth site, Rattlesnake Creek near Macksville (station 07142300), also can be categorised as least disturbed as the majority of the metrics (26 of 29) were neither diminished nor inflated (Table 3). For these four least-disturbed sites, the O/E values for the mean monthly flows typically were within ±20% of one (Figure 3).

Along the South Fork Ninnescah River, different flow conditions were indicated for the two sites. At the upstream site near Pratt (station 07144910), a mix of diminished (seven metrics), inflated (eight metrics), and least-disturbed (14 metrics) conditions was indicated. For the downstream site near Murdock (station 07145200), the majority of the metrics (20 of 29) indicated an inflated condition (Table 3). At this site, the O/E values for the mean monthly flows averaged 85% greater than 1 (range, 43% in July to 137% in January and December; Figure 3). The inflated condition at Murdock likely is related to the fact that the South Fork Ninnescah River is a gaining stream (i.e., its flow increases in response to groundwater discharges) along the reach between Pratt and Murdock (Gillespie & Hargadine, 1994). Thus, the inflated condition is natural and does not indicate anthropogenic alteration. At Murdock, E was underpredicted likely because the model used does not effectively account for groundwater contributions at the local scale. This basin is mostly unaffected by groundwater-level changes associated with pumping from the High Plains aquifer (Figure 2).

For the remaining three sites, a likely or possible diminished condition was indicated that probably is a consequence of substantial declines in groundwater levels (McGuire, 2014) caused by extensive pumping from the High Plains aquifer (Figure 2). At the Cimarron River near Forgan site (station 07156900, hereafter Forgan), the majority of the metrics (16 of 29) indicated a diminished condition (Table 3). According to Young et al. (2005), groundwater-level declines have resulted in decreased flow in the Cimarron River. Within the Cimarron River Basin, at the Crooked Creek near Englewood site (station 07157500, hereafter Englewood), a possible diminished condition was indicated (11 of 29 metrics; Table 3). Upstream from the Forgan and Englewood sites, there are extensive areas with groundwater-level declines of 15 to 45 m (50 to 150 ft) or more (Figure 2). A possible diminished condition (12 of 29 metrics) also was indicated for the Rattlesnake Creek near Zenith site (station 07142575, hereafter Zenith; Table 3). For these three sites, the O/E values for the mean monthly flows frequently were much less than 1 (Figure 3).

Discussion of O/E values for the annual flow metrics is focused on the four sites that were not categorised as least disturbed, namely, Englewood, Forgan, Pratt, and Zenith. A fifth site, Murdock, is not included in the following discussion because its flow condition is naturally inflated. Unless otherwise stated, the condition for a specific annual flow metric at a specific site is least disturbed.

Median annual flow (P50) was diminished at Forgan. Tenth percentile flow (P10) was inflated at Pratt and diminished at Englewood. Ninetieth percentile flow (P90) was diminished at Forgan and Zenith. Without exception, cases of diminished median annual, 10th percentile, and 90th percentile flow occurred at sites with substantial upstream declines in groundwater levels (Figure 2). Variation of daily flows (CV_FLOW) was diminished at Forgan. Baseflow percentage of flow (PER_BSFL) was diminished at Forgan and Pratt (Table 3).

Alteration of the number of flow pulses was most pronounced for low-flow events. The average annual number of flow pulses less than

TABLE 3 Observed/expected (O/E) ratios for the 29 flow metrics assessed in this study

Streamgage	P50	P10	P90	CV_FLOW	PER_BSFL	AVG_JAN	AVG_FEB	AVG_MAR
07142300	1.063	1.294	0.931	1.114	0.812	1.090	0.872	0.987
07142575	0.648	0.650	**0.599**	0.900	0.979	0.669	0.609	**0.503**
07144780	1.085	0.891	0.944	0.887	1.036	1.106	1.114	0.975
07144910	1.15	*2.201*	0.620	0.623	**0.212**	1.113	0.908	0.947
07145200	*2.534*	*3.390*	*1.617*	**0.570**	0.698	*2.372*	*1.995*	*1.546*
07149000	1.188	1.001	1.071	0.978	0.943	1.167	1.161	1.028
07151500	1.205	1.198	1.060	0.910	0.896	1.089	1.018	1.041
07156900	**0.517**	0.788	**0.522**	**0.411**	**0.114**	1.101	1.228	0.645
07157500	1.005	**0.471**	0.801	1.162	0.888	0.676	**0.531**	**0.379**
Streamgage	AVG_APR	AVG_MAY	AVG_JUN	AVG_JUL	AVG_AUG	AVG_SEP	AVG_OCT	AVG_NOV
07142300	0.887	0.910	0.886	0.913	0.810	1.251	0.869	0.807
07142575	**0.533**	0.633	**0.597**	0.915	**0.387**	0.802	**0.471**	**0.415**
07144780	0.972	1.030	0.924	0.988	1.182	0.998	1.116	0.955
07144910	0.987	1.023	0.739	1.326	*1.857*	0.935	0.971	0.963
07145200	*1.527*	*1.562*	*1.503*	*1.434*	*1.940*	*1.940*	*1.949*	*2.003*
07149000	1.110	1.194	1.088	0.978	1.153	1.168	1.228	1.084
07151500	0.995	1.088	1.075	1.073	1.153	1.122	1.080	1.108
07156900	0.943	**0.456**	**0.214**	**0.226**	**0.253**	**0.363**	**0.414**	**0.522**
07157500	**0.578**	0.799	**0.437**	**0.598**	0.830	0.895	0.887	0.888
Streamgage	AVG_DEC	PUL_NO_P10	PUL_NO_P25	PUL_NO_P75	PUL_NO_P90	PUL_LEN_P10	PUL_LEN_P25	PUL_LEN_P75
07142300	1.078	0.789	**0.589**	0.724	0.708	0.969	1.352	1.367
07142575	0.665	*1.731*	1.024	0.885	0.887	**0.417**	0.749	0.756
07144780	1.105	0.933	0.963	1.002	1.000	0.960	0.883	0.926
07144910	1.049	*2.399*	*1.636*	*1.819*	*1.708*	**0.382**	**0.453**	**0.281**
07145200	*2.368*	*1.523*	*1.456*	1.334	1.283	0.713	0.733	0.622
07149000	1.119	0.848	1.012	1.007	1.046	1.105	0.979	0.926
07151500	1.098	1.076	1.054	1.028	1.017	0.981	0.883	0.847
07156900	1.047	*3.083*	*2.622*	1.255	*1.407*	0.628	**0.535**	**0.523**
07157500	0.770	*2.503*	*1.591*	1.269	1.224	0.773	0.805	**0.566**
Streamgage	PUL_LEN_P90	PUL_FLOW_P10	PUL_FLOW_P25	PUL_FLOW_P75	PUL_FLOW_P90			
07142300	1.365	**0.004**	**0.391**	0.797	0.949			
07142575	0.662	**0.199**	**0.369**	**0.412**	**0.439**			
07144780	0.938	0.743	1.117	0.984	0.944			
07144910	**0.350**	*2.448*	*2.023*	**0.595**	**0.571**			
07145200	0.647	*5.573*	*3.389*	*1.402*	1.373			
07149000	0.932	0.626	0.955	1.039	1.003			
07151500	0.860	1.179	1.202	0.931	0.951			
07156900	**0.457**	0.665	0.907	**0.159**	**0.153**			
07157500	0.633	**0.108**	**0.598**	**0.331**	**0.324**			

Diminished values are shown in bold.
Inflated values are shown in italics.

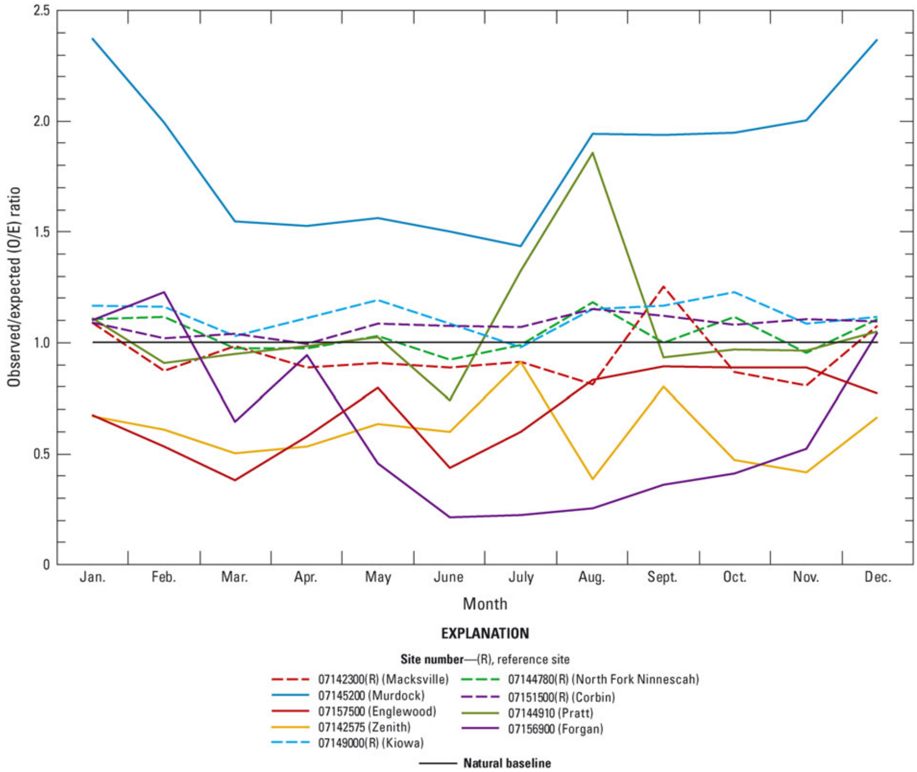

FIGURE 3 Observed/expected (O/E) ratio for mean monthly flow normalised by drainage area for the nine selected U.S. Geological Survey streamgages [Colour figure can be viewed at wileyonlinelibrary.com]

the 10th percentile (PUL_NO_P10) was inflated for all four sites. With the exception of Zenith, the average annual number of pulses less than the 25th percentile (PUL_NO_P25) also was inflated. Less alteration was indicated for high-flow events. Pratt is the only site for which the average annual number of flow pulses larger than the 75th percentile (PUL_NO_P75) was inflated. An inflated condition for the average annual number of flow pulses larger than the 90th percentile (PUL_NO_P90) was indicated for Forgan and Pratt; although, for Forgan, the O/E value barely exceeded the 40% threshold (Table 3). There were no diminished cases for the number of pulses.

Across the range of flow conditions investigated, the duration of flow pulses frequently was diminished. The average duration of pulses less than the 10th percentile (PUL_LEN_P10) was diminished at Pratt and Zenith. The average duration of pulses less than the 25th percentile (PUL_LEN_P25) was diminished at Forgan and Pratt. A diminished condition for the average duration of pulses larger than the 75th percentile (PUL_LEN_P75) was indicated for Englewood, Forgan, and Pratt. For the average duration of pulses larger than the 90th percentile (PUL_LEN_P90), a diminished condition was indicated for Forgan and Pratt (Table 3). There were no inflated cases for the duration of pulses.

Alteration of the average flow of pulses varied with magnitude. The average flow of pulses less than the 10th percentile (PUL_FLOW_P10) was diminished at Englewood and Zenith but inflated at Pratt. Likewise, the average flow of pulses less than the 25th percentile (PUL_FLOW_P25) was diminished at Englewood and Zenith but inflated at Pratt; although, for Englewood, the O/E value barely exceeded the 40% threshold. For the average flow of pulses larger than the 75th percentile (PUL_FLOW_P75), a diminished condition was indicated for Englewood, Forgan, Pratt, and Zenith. However, for Pratt, the O/E value barely exceeded the 40% threshold. The average flow of pulses larger than the 90th percentile (PUL_FLOW_P90) was diminished for all four sites (Table 3). Generally, diminished average flow of pulses occurred at sites with substantial upstream declines in groundwater levels (i.e., Englewood, Forgan, and Zenith; Figure 2).

Overall, for the four sites, the number of extreme flow events increased (as indicated by increases in both the number of low- and high-flow pulses). This was especially true for low-flow events. However, the duration of extreme flow events often decreased. Flow magnitude for low-flow events either increased or decreased, whereas the magnitude for high-flow events decreased (Table 3).

3.3 | Management ramifications

In terms of habitat, darters typically prefer small spring-fed streams with clear, shallow, cool, slow-moving water and aquatic vegetation (Layher, 2002; Moss, 1981). The viability of these important habitats is threatened in areas where groundwater-level declines are pronounced and ongoing. It is also known that darters may be tolerant of suboptimal conditions, at least temporarily, including turbid water (Matthews & McDaniel, 1981) and extremes of hyperthermia and hypoxia (Labbe & Fausch, 2000; Smith & Fausch, 1997). During dry periods, darters rely on remnant in-channel pools as refugia for survival (Labbe & Fausch, 2000). If conditions are acceptable, they also may inhabit larger streams (Eberle & Stark, 2000; Layher, 2002).

Darters likely exist as a metapopulation, the viability of which depends on stream connectivity for migration, colonisation of new habitats, and recolonisation of former habitats (Fitzpatrick, Crockett, & Funk, 2014). Fragmentation increases local extinction risk by isolating upstream populations and reducing the potential for recolonisation (Falke et al., 2011; Fitzpatrick et al., 2014). Moreover, as the isolation of populations increases, the risk of metapopulation collapse also increases (Fagan, Unmack, Burgess, & Minckley, 2002; Hanski, 1998).

Flow alteration, in particular flow depletion, can degrade or eliminate darter habitat. Within the study area, flow depletion is most pronounced in the Cimarron River Basin. At Forgan, a diminished condition was indicated for 16 of 29 flow metrics (Table 3). At Englewood, a diminished condition was indicated for several mean monthly flows and high-flow metrics. At both sites, the number of low-flow events increased as indicated by increases in the occurrence of pulses less than the 25th and 10th percentiles (Table 3).

Diminished flow conditions in the Cimarron River Basin also were reported by Juracek (2015). For annual flow metrics at Forgan (period of record 1966 to 2013), a statistically significant (*p* value <.001) decreasing trend was determined for mean flow, mean baseflow, 90th percentile flow, 10th percentile flow, minimum 7-day mean flow, and minimum 28-day mean flow. Annual 90th percentile flows decreased from about 3.4 m^3/s to about 0.8 m^3/s. At Englewood (period of record 1943 to 2013), annual flow metrics with a statistically significant decreasing trend (*p* value <.001) were mean flow, mean baseflow, and 90th percentile flow (Juracek, 2015). If the documented decreasing trends in annual mean flow at Forgan and Englewood continue, the flow at these two sites eventually may cease at some point in the future. Extrapolation of the recent (post-2000) trends indicates the possibility that annual mean flow at Forgan and Englewood may drop to zero within the next decade or two.

Flow depletion also is evident in the Rattlesnake Creek Basin. At Zenith, a diminished condition was indicated for 12 of 29 flow metrics (Table 3). Moreover, at Zenith (period of record 1974 to 2013), annual flow metrics with a statistically significant decreasing trend (*p* value ≤.05) were mean baseflow, 10th percentile flow, minimum 7-day mean flow, and minimum 28-day mean flow. Upstream at Macksville (period of record 1960 to 2013), annual flow metrics with a statistically significant decreasing trend (*p* value <.01) were mean flow, mean baseflow, 90th percentile flow, 10th percentile flow, minimum 7-day mean flow, and minimum 28-day mean flow (Juracek, 2015). However, since 1980, well-defined trends at these two sites are not evident.

As pertaining to the availability and quality of darter habitat in the Cimarron River and Rattlesnake Creek Basins, flow depletion is a management concern for several reasons. Primary issues include stream connectivity, pool habitat, and water temperature. Connectivity is important for darter dispersal, colonisation, and reproduction (Groce, Bailey, & Fausch, 2012; Labbe & Fausch, 2000; Taber, Taber, & Topping, 1986), and darters have been found to be more prevalent in less fragmented streams (Groce et al., 2012). Moreover, Fitzpatrick et al. (2014) determined that available stream habitat and connectivity had a positive influence on genetic diversity for darters. With ongoing flow depletion, connectivity eventually is reduced and darter populations may become fewer, more isolated, and at greater risk for extirpation. Within a basin, decreasing flow eventually will result in a decrease in habitat (availability and quality) in the smaller tributaries; however, in the larger streams, a simultaneous increase in suitable habitat is possible, at least temporarily. Eberle and Stark (2000), citing several sources, noted that darters have been collected in the Arkansas and Cimarron Rivers and that their presence in these larger streams may, in part, be a function of reduced flows that created conditions more favorable for darter habitation (e.g., shallower, slower-moving water).

Pool habitat likewise is flow dependent. Pools are created and maintained by periodic high flows (e.g., floods). Declining high flows, evidenced by the decrease in magnitude of 90th percentile flows, eventually may affect the availability and quality of pools. With declining high flows, existing pools may not be maintained and new pools may not be created. Further, declining groundwater levels associated with excessive pumping of the High Plains aquifer may reduce or eliminate the ability of baseflow to sustain pools during dry periods. The combination of reduced high flows and reduced baseflow may result in fewer and shallower pools that may completely freeze in winter and kill any resident darters (Labbe & Fausch, 2000).

Water temperature is a third flow-related concern. Darters generally prefer a water temperature of 25 °C or less (Eberle & Stark, 2000). Spawning occurs repeatedly from mid-February to mid-July when water temperatures range from 9 to 17 °C (Taber et al., 1986). Flow depletion results in shallower water depths and increased heating. In addition, the aforementioned drop in groundwater levels results in a reduced contribution of cool groundwater to streams thus increasing summer water temperatures (Eberle & Stark, 1998). Although darters can temporarily survive high temperatures (Smith & Fausch, 1997), more frequent and persistent elevated temperatures may exceed their tolerance level. Increased water temperatures also can reduce the time available for spawning. Finally, increased water temperatures decrease the availability of dissolved oxygen at the same time that aquatic organism demand for oxygen increases (Allan & Castillo, 2007).

In sum, based on the O/E results, it is concluded that flow alteration (depletion) likely has caused a decline in the availability and quality of darter habitat in the Cimarron River Basin and a possible decline in the Rattlesnake Creek Basin. The primary cause of habitat loss is irrigation development using groundwater (Layher, 2002, citing several studies). For the North Fork Ninnescah, South Fork Ninnescah, Medicine Lodge, and Chikaskia River Basins, the availability and quality of darter habitat may be minimally affected by flow alteration. Thus, it is within these latter four basins where the best potential for preserving darter habitat may exist. As noted by Dodds, Gido, Whiles, Fritz, and Matthews (2004), effective conservation of stream habitat may require the protection of entire basins containing up to fourth- or fifth-order stream channels. Given the low success rate of translocations to create self-sustaining darter populations (Groce et al., 2012), the most effective strategy may be to focus on the protection and restoration of sites with existing populations and increasing the connectivity among them (Fitzpatrick et al., 2014).

Global warming during the 21st century is projected to result in minimal change in average annual precipitation in the study area; although, the amount of precipitation in individual storm events may increase (Walsh et al., 2014). Increased temperature may result in increased evapotranspiration. Thus, in the study area, global warming may contribute to flow depletion but to an uncertain degree. Dhungel, Tarboton, Jin, and Hawkins (2016) state that "given the uncertainty in the magnitude of future emissions of greenhouse gases and differences between climate models in their specific predictions, it is impossible to predict with certainty how the flow regimes in streams of the USA and elsewhere will change." Of more immediate concern in the study area is the likelihood that groundwater withdrawals for irrigation will continue to adversely affect streamflow and the availability and quality of darter habitat. In particular, if groundwater withdrawals for irrigation continue in the future at a rate similar to the recent past, habitat conditions in the affected areas likely will continue to decline.

4 | SUMMARY AND CONCLUSIONS

Management of stream habitat for a threatened fish species requires an understanding of flow conditions and how those conditions may have changed over time. To provide some of the information required for the future management of the threatened Arkansas darter (*Etheostoma cragini*) in Kansas, flow alteration was assessed for nine streamgage sites located in priority basins within the historical range of the darter. For each site, flow was assessed using 29 metrics that together were considered sufficient to provide an ecologically meaningful assessment of flow alteration. For each metric, the assessment involved a comparison of the observed (O) with the predicted expected (E) reference condition to determine if the observed condition was diminished, inflated, or least disturbed.

The O/E results indicated a likely or possible diminished condition for flow in the Cimarron River and Rattlesnake Creek Basins. Within these basins, the primary cause of flow depletion is groundwater-level declines that are a result of groundwater pumping for irrigated agriculture. As groundwater pumping continues, it is anticipated that habitat for the darter in these two basins will continue to be degraded and (or) eliminated. Habitat characteristics adversely affected by flow depletion may include stream connectivity, pools, and water temperature.

Basins minimally affected, or unaffected, by flow depletion were the North and South Fork Ninnescah, Medicine Lodge, and Chikaskia Rivers. Although, flow conditions in the upstream part of the North Fork Ninnescah River Basin possibly have been affected by groundwater-level declines. These four basins may offer the best opportunity for the preservation of darter habitat.

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APPENDIX

MODEL PERFORMANCE CRITERIA

Metric name	Bias[a]	Mean O/E[b]	SD O/E[c]	NSE[d]	Comp[e]	ModelPerf[f]
P50	0.37	0.92	0.43	0.93	3.419	Very good
CV_FLOW	−0.58	0.99	0.23	0.78	3.531	Very good
AVG_JAN	−1.06	0.95	0.48	0.96	3.413	Very good
AVG_FEB	−0.53	0.96	0.45	0.95	3.460	Very good
AVG_MAR	−0.60	0.97	0.56	0.94	3.356	Good
AVG_APR	−1.31	0.95	0.35	0.93	3.512	Very good
AVG_MAY	−1.49	0.95	0.39	0.87	3.409	Very good
AVG_JUN	−1.26	0.95	0.44	0.88	3.385	Good
AVG_JUL	1.51	0.96	0.47	0.87	3.355	Good
AVG_AUG	3.45	0.97	0.53	0.80	3.202	Good
AVG_SEP	2.52	0.97	0.55	0.79	3.180	Good
AVG_OCT	0.93	0.97	0.48	0.88	3.362	Good
AVG_NOV	−0.42	0.94	0.43	0.95	3.459	Very good
AVG_DEC	−1.37	0.94	0.46	0.95	3.417	Very good
PUL_NO_P90	0.25	0.98	0.26	0.82	3.540	Very good
PUL_NO_P75	0.43	0.98	0.26	0.81	3.529	Very good
PUL_NO_P25	2.22	1.01	0.55	0.57	2.985	Fair
PUL_NO_P10	0.77	1.01	0.80	0.54	2.712	Fair
P10	2.15	0.87	0.63	0.77	2.997	Fair
P90	−1.59	0.94	0.32	0.94	3.550	Very good
PER_BSFL	−5.96	0.89	0.85	0.07	2.051	Poor
PUL_LEN_P10	−3.03	0.96	0.38	0.45	3.000	Fair
PUL_LEN_P25	−4.85	0.95	0.35	0.49	3.049	Fair
PUL_LEN_P75	−3.04	0.96	0.36	0.69	3.269	Good
PUL_LEN_P90	−2.79	0.96	0.36	0.72	3.293	Good
PUL_FLOW_P10	2.04	0.85	0.63	0.76	2.964	Fair
PUL_FLOW_P25	2.39	0.89	0.58	0.80	3.090	Fair
PUL_FLOW_P75	−1.17	0.97	0.33	0.94	3.572	Very good
PUL_FLOW_P90	−1.22	0.97	0.33	0.94	3.573	Very good

[a]Bias = Percent bias (Moriasi et al., 2007). Unstandardized values.

[b]Mean O/E = Mean observed (O) divided by expected (E) values (i.e., O/E ratio; Carlisle et al., 2011). Unstandardized values.

[c]SD O/E = Standard deviation of O/E values. Unstandardized values.

[d]NSE = Nash-Sutcliffe efficiency (Nash & Sutcliffe, 1970). Unstandardized values.

[e]Comp = Composite performance criterion (0 to 4, higher score indicates superior performance).

[f]ModelPerf = Model performance: very good (comp ≥ 3.40), good (3.10 ≤ comp < 3.40), fair (2.70 ≤ comp < 3.10), and poor (comp < 2.70), from table 1 in Eng et al., Freshwater Sciences, in press.